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# ⇒ Wireless Power Transmission from Satellite to rover

* **Objective**: Transmitting power wirelessly from the orbiter to the rovers.

* To generate power from electromagnetic wave, the high frequency transmitted signal needs to be rectified at the receiver end.

## ANTENNAS :-

* Antenna is a resonator which has a particular resonating frequency through which it can transmite (or) receive.

• Amount of power received at the receiver end is calculated as follows:

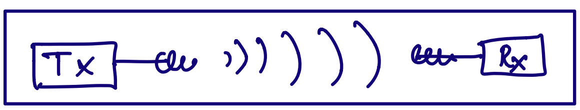
## Friis Transmission Equation :-

$$P_r = \frac{\lambda^2 G_r G_t}{(4\pi D)^2} = \frac{A_r A_t}{(\lambda D)^2} P_t$$

$$\eta = \frac{P_r}{P_t} = 1 - e^{-P_r}$$

$P_t$ = Power at transmission
$P_r$ = Power at Reception
$G_t$ = transmitter antenna gain
$G_r$ = Receiver antenna gain
$A_t$ = transmitting antenna aperture area.
$A_r$ = Receiving antenna aperture area.
$\lambda$ = wavelength in meters
$D$ = Distance b/w antennas.

⇒ Friis Eq calculation :-




* Power density 'w' at receiver end Rx ⇒ $\frac{\text{Power Transmitted}}{\text{Area}} = \frac{P_T}{4\pi d^2}$ [∵ Area is sphere] — ①

* If gain $G_T$ at transmitter is considered ⇒ $w = \left[\frac{P_T}{4\pi d^2}\right] G_T$ — ②

gain $G_T = \frac{4\pi(\text{effective aperture of } A_T)}{\lambda^2}$

$= \frac{4\pi A_T}{\lambda^2}$ — ③

∴ Power Received at Rx is

$$P_r = P_T\left[\frac{\cancel{4\pi} A_T}{\lambda^2} \times \frac{1}{\cancel{4\pi} d^2}\right] = \frac{P_T A_T}{(\lambda d)^2} \quad \text{— ④}$$

If Affective aperture of Rx at ideal condition is $A_R$

$$\therefore \boxed{P_r = \left[\frac{A_R A_T}{\lambda d^2}\right] P_T} \quad - (5)$$

⇒ If we consider '$A_R$' as affective aperture of Receiving Antenna.

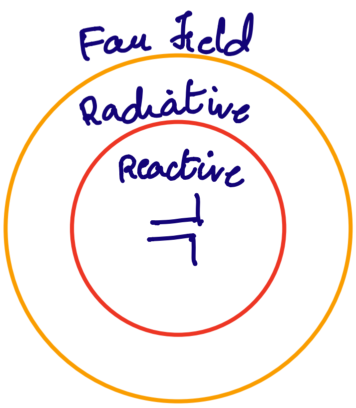
$$A_R = \frac{\lambda^2}{4\pi} G_R \quad [G_R = \text{Directive gain of Receiving Antenna}]$$

$$\therefore P_r = \frac{P_T}{4\pi d^2} G_T A_R \xrightarrow{} \text{at receiving end} = \frac{\lambda^2 G_T G_R}{(4\pi d)^2} \cdot P_T$$

$$\therefore \boxed{P_r = \frac{\lambda^2 G_T G_R}{(4\pi d)^2} \cdot P_T}$$

⇒ Power loss during transmission ⇒ $P_T - P_r$ = Path Loss

# ⇒ Antenna Communication Fields




* Various fields of antenna depend on the length of antenna

⇒ If length of Antenna is '$L$' & Radius of field region is '$R$'

then Reactive Near Field ⇒ if; $R < 0.62\sqrt{\frac{L^3}{\lambda}}$

Radiative Near Field ⇒ if; $0.62\sqrt{\frac{L^3}{\lambda}} < R < \frac{2L^2}{\lambda}$

Far Field ⇒ if; $R > \frac{2L^2}{\lambda}$

* Our field of interest is "Far Field Region" where $R > \frac{2L^2}{\lambda}$

Properties of Far Field :- ① Wavefront ≈ plannar

② Radiation pattern is completely formed

③ Electric field & Magnetic field vectors as $\perp$er to eachother.

## ⇒ Power Dissipation in Antenna

* When power is supplied to antenna it is dissipated in two ways:-

 ① Radiation ② Ohmic loss.

* if we supply current '$I$' then power dissipated ⇒ $P = I^2 R$ [R = Radiation Resistance]

 ① Radiative Power ⇒ $P_{rad} = I^2 R_r$ [$R_r$ = Radiation Resistance]

 ② Ohmic loss ⇒ $P_{Loss} = I^2 R_L$ [$R_L$ = Load resistance of Antenna] +

Total Power ⇒ $P_T = P_{rad} + P_{Loss} = I^2 [R_r + R_L]$

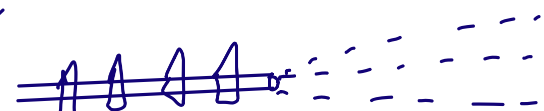
* Efficiency of Radiation $E_{rad} = \dfrac{R_r}{R_r + R_L}$ ∴ $\boxed{\begin{array}{l} P_{rad} \propto R_r \\ E_{rad} \propto R_r \end{array}}$

∴ Radiation Resistance depends on:-

 ① Antenna Configuration
 ② Ratio of Length to diameter of conductor used in antenna
 ③ Depends on point where radiation resistance is considered
 ④ Location of antenna with respect to ground (or) other objects
 ⑤ Corona discharge.

| |
|---|
| NOTE:- An Isotropic source radiates equally in all directions |

⇒ Antenna ⇒ Directional



Gain = 3dB = factor ②

4W Prad.

⇒ 6dBs

⇒ Center field dipole (Long Wave) antenna

⇒ Nicola Tesla failed because he used low frequencies i.e $f \propto \frac{1}{\lambda}$ hence $\lambda$ was longer than expected. So; as $\lambda \propto \frac{1}{\tau^2}$ ; this lead to lower efficiency $\eta$ from (3).

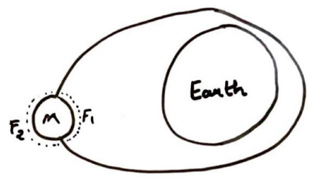
*But in 1970's Dr. William Brown was successful in demonstrating Wireless Power Transfer as he used high frequency waves which lead to longer $\eta$.

## Wireless Power Transmission

⇒ Geosynchronous Orbit Calculation:

- $F_1$ persists for the complete Moon Orbital Time Period $T_M = 27.322$ days

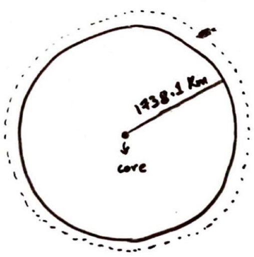
Hence Rotation $r_0 = T_m$ [Due to earth gravitation the $F_1$ is tidally locked]




$F_1$ = near View

$F_2$ = Far View.

* Gravitational force $g_m = 1.62\ m/s^2$ ; * Mass $M_m = 7.35 \times 10^{22}$ Kg




Radius $R_m = 1,738.1$ Km [Equitorial Radius]

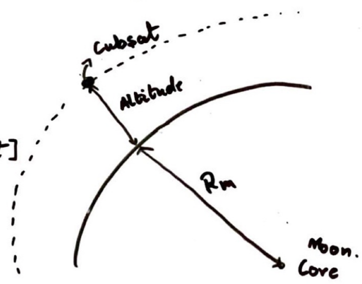
Rotational Time Period ⇒ $Y_{om}$ = 27.3 days. = 655.2 hours

Semi-Major Axis ⇒ $a_m = 3.844 \times 10^8$ m

Universal Gravitational Constant = $G = 6.67 \times 10^{-11}\ N \cdot m^2/Kg^2$

$F_1$ ⇒ Visible face for total time period $T_M$

$F_1$ ⇏ $\infty$ face visibility.




$$F_g = ma_c \Rightarrow [a_c = r\omega^2] \Rightarrow F_g = mr\omega^2 \ [\ \omega = \text{Angular Velocity of Cubsat}]$$

$$\Rightarrow \omega = \frac{\text{change in Angular Position}}{\text{change in Time}} = \frac{\Delta\theta}{\Delta t} = \frac{2\pi}{T_m} = \frac{2\pi}{655.2} \times \frac{1}{(3600)} = 2.663811435 \times 10^{-6}\ \text{rad/sec}$$

$$\therefore \frac{G M_m \cancel{m_s}}{r^2} = \cancel{m_s} r\omega^2 \Rightarrow r = \sqrt[3]{\frac{GM_m}{\omega^2}} = \sqrt[3]{\frac{6.67 \times 10^{-11} \times 7.35 \times 10^{22}}{2.663811435 \times 10^{-6}}} = 88403353.2\ m = 88403.3532\ Km$$

$$= \underline{88403353.2\,m}$$

[$m_s$ = Cubsat mass]

Altitude = $r - R_m$ = 88403.3532 − 1738.1 = $\underline{\underline{86,665.2532\ Km}}$ = $\underline{\underline{8,66,65,253.2\ m}}$

velocity = 235.489736287692 m/s

= 0.235489736287692 Km/s

$V = r\omega$

r = meters

ω = rad/sec

⇒ Calculation of necessary radius vector '$\vec{r}$' & velocity vector '$\vec{v}$' for calculating accurate Right Ascension of Ascending Node (RAAN).

⇒ **Radius Vector :-**

'r' from Origion $= 88403{\cdot}3532$ Km $= \sqrt{7815152857}$

$= (2605050952{\cdot}33) \times 3$

$$\boxed{\therefore\ \vec{r} = 2605050952{\cdot}33\,\hat{I} + 2605050952{\cdot}33\,\hat{J} + 2605050952{\cdot}33\,\hat{K}}$$

⇒ **Velocity Vector :-**

'v' of satellite $= 0{\cdot}235489736287692$ Km/s $= \sqrt{0{\cdot}0554554159}$

$= \sqrt{(0{\cdot}01848513863) \times 3}$

$$\boxed{\therefore\ \vec{v} = 0{\cdot}01848513863\,\hat{I} + 0{\cdot}01848513863\,\hat{J} + 0{\cdot}01848513863\,\hat{K}}$$

⇒ **Specific Angular Momentum :-** 'h'

$$h = r \times v = \begin{vmatrix} \hat{I} & \hat{J} & \hat{K} \\ 3650893235{\cdot}33 & 2025186793{\cdot}33 & 2139072828{\cdot}33 \\ 0{\cdot}01848513863 & 0{\cdot}01848513863 & 0{\cdot}01848513863 \end{vmatrix}$$

$x = -46597812 4$ $\quad y = -579864159$ $\quad$ [Self Intuition]

$$h = -2105199{\cdot}145\,\hat{I} - 27946209{\cdot}81\,\hat{J} + 30051408{\cdot}95\,\hat{K}$$

⇒ **Nodal Vetor at Ascending Node**

$$\vec{N} = \hat{K} \times \vec{h} = \begin{vmatrix} \hat{I} & \hat{J} & \hat{K} \\ 0 & 0 & 1 \\ h_I & h_J & h_K \end{vmatrix}$$

$$\vec{N} = \begin{vmatrix} \hat{I} & \hat{J} & \hat{k} \\ 0 & 0 & 1 \\ -2105199.145 & -27946209.81 & 30051408.95 \end{vmatrix}$$

$$\vec{N} = 27946209.81 \; \hat{I} + 2105199.145 \; \hat{J}$$

$\therefore$ Magnitud of $\vec{N} = \|\vec{N}\| = \sqrt{(27946209.81)^2 + (2105199.145)^2}$

$$= 28025390.38$$

$\therefore$ Right Ascension of Ascending Node $\Rightarrow \cos\Omega = \dfrac{N_I}{N}$ (or) $\dfrac{N_x}{N}$

$$\Omega = \cos^{-1}\left[\frac{27946209.81}{28025390.38}\right] = 0.07518838887 \text{ rad}$$

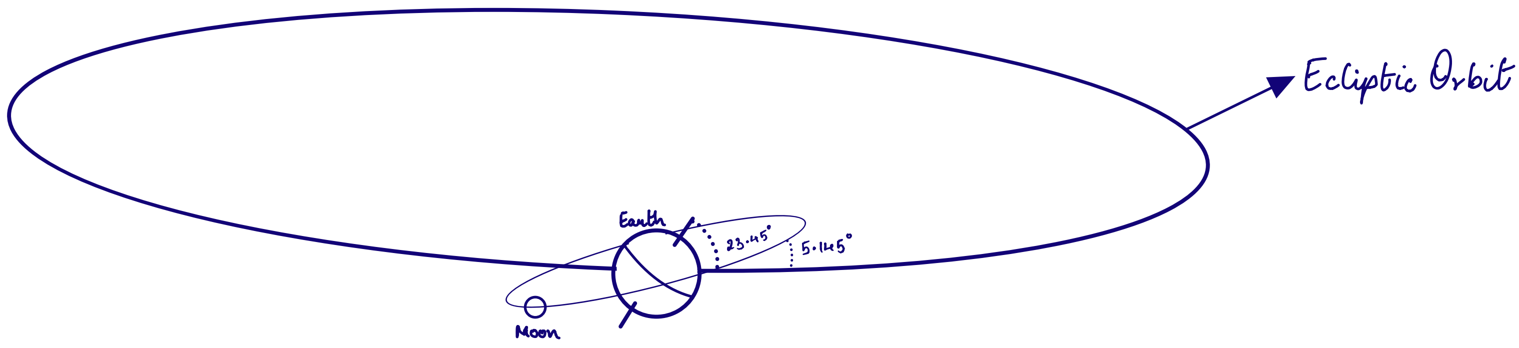
$$= 4.30797735065\,0099^\circ \,//$$

$$\beta(t) = \sin^{-1}\left(\cos(1.548)\sin(21.902)\sin(4.308) + \sin(1.548)\cos(21.902)\right)$$

$= 0.053$ rad $= \underline{\underline{3.04^\circ}}$ Random Assumption.

## ⇒ Beta angle calculation :-

* Inclination of Moon orbit with Ecliptic orbit




* Angle of inclination b/w Moon Orbit & Ecliptic Orbit = $\underline{\underline{5.145^\circ}}$

## ⇒ Solar Vector calculation :-

$$\hat{s} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\varepsilon & -\sin\varepsilon \\ 0 & \sin\varepsilon & \cos\varepsilon \end{bmatrix} \begin{bmatrix} \cos\Gamma & -\sin\Gamma & 0 \\ \sin\Gamma & \cos\Gamma & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{Bmatrix} 1 \\ 0 \\ 0 \end{Bmatrix} = \begin{Bmatrix} \cos\Gamma \\ \sin\Gamma\cos\varepsilon \\ \sin\Gamma\sin\varepsilon \end{Bmatrix}$$

$\varepsilon$ = Angle of inclination between equatorial plane & Orbital plane

Gamma = $\Gamma$ = Ecliptic True Solar Longitude

## ⇒ Orbit Vetor :-

$$\hat{O} = \begin{bmatrix} \cos\Omega & -\sin\Omega & 0 \\ \sin\Omega & \cos\Omega & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos i & -\sin i \\ 0 & \sin i & \cos i \end{bmatrix} \begin{Bmatrix} 0 \\ 0 \\ 1 \end{Bmatrix} = \begin{Bmatrix} \sin\Omega\sin i \\ -\cos\Omega\sin i \\ \cos i \end{Bmatrix}$$

$i$ = Angle of inclination between equatorial plane & orbital plane

$\Omega$ = Right ascension of ascending node.

$$\cos\left(\theta - \frac{\pi}{2}\right) = \cos\theta \cos\frac{\pi}{2} + \sin\theta \sin\frac{\pi}{2}$$

$$= 0 + (1)\sin\theta = \sin\theta$$

Helios sphere

$\Rightarrow$ Orbital period of Moon is $= 27.3$ days

$$\beta(t) = \sin^{-1}\left( \cos(\delta_s(t)) \sin i \sin(\Omega(t) - \Omega_s(t)) + \sin(\delta_s(t)) \cos(i) \right)$$

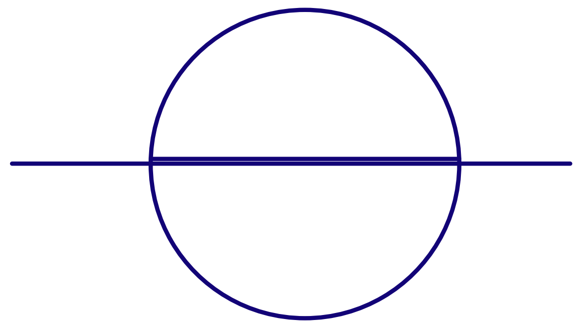
$\delta_s(t)$ = Declination of Sun

$i$ = Inclination of Orbit

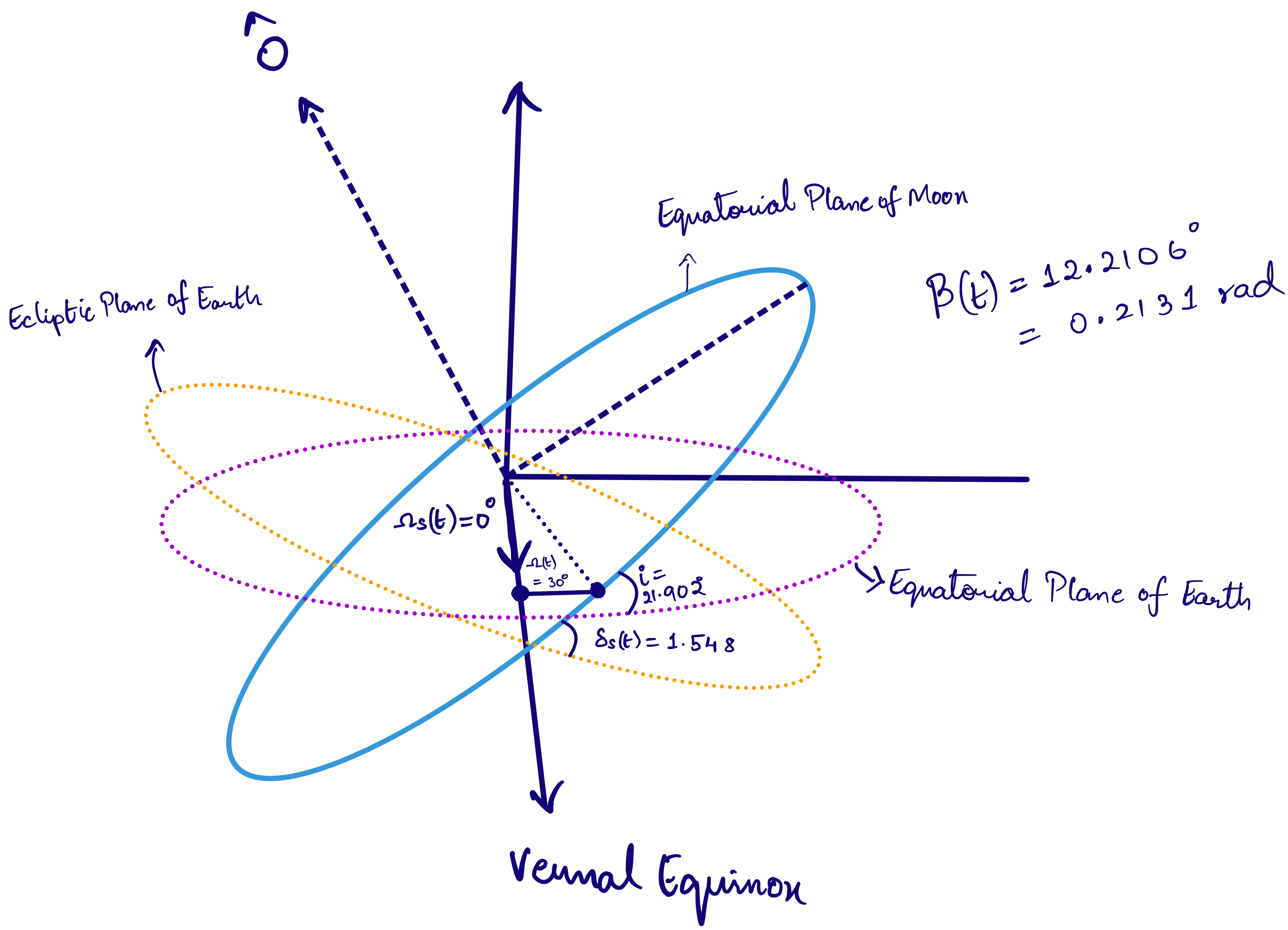
$\Omega(t)$ = Position of Ascending node

$\Omega_s(t)$ = Right Ascension of Sun

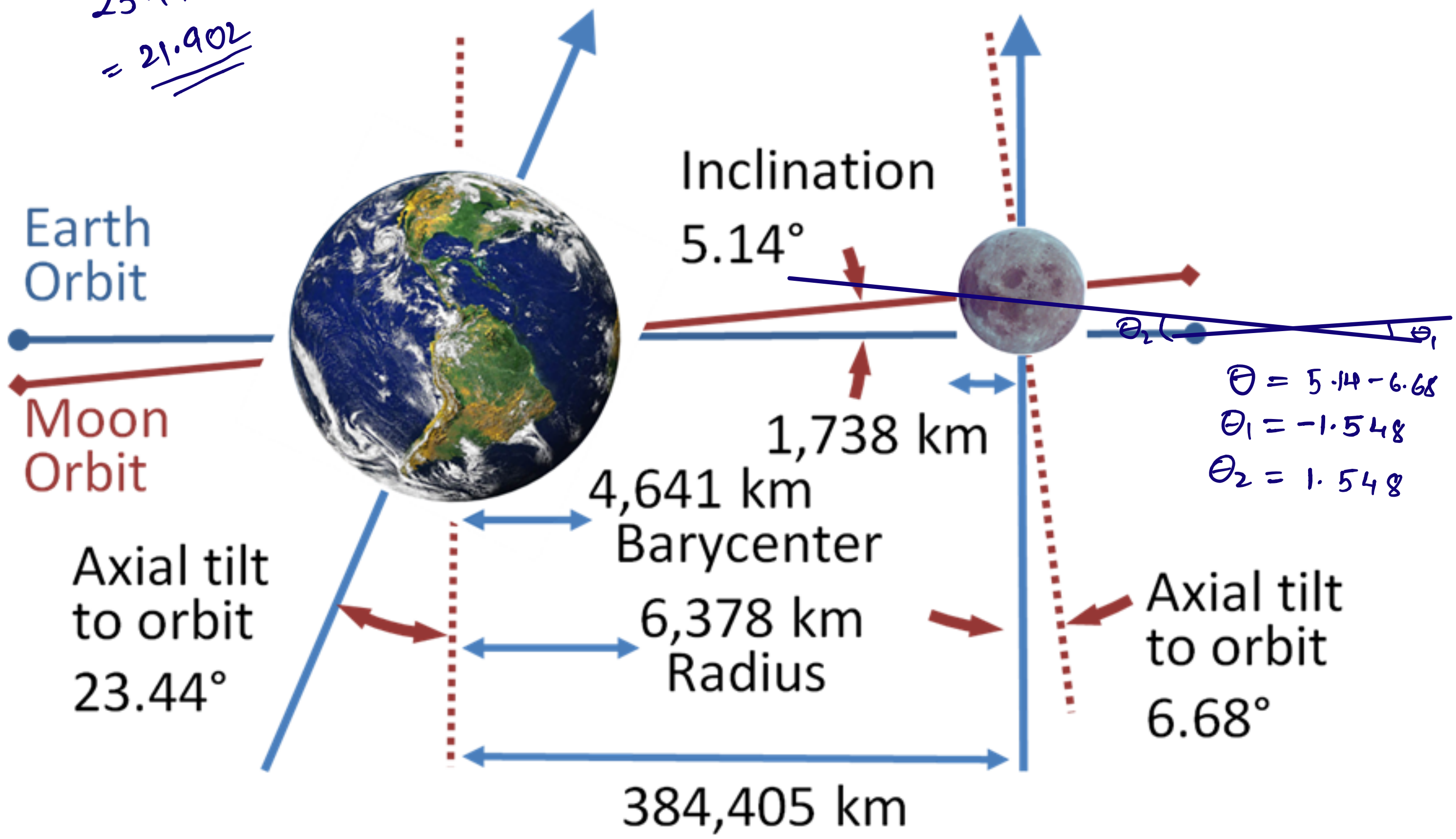
$\beta(t)$ = Beta Angle



$$\delta_s(t) \approx \frac{360}{27.3 \text{ days}} = \frac{13.187^\circ}{\text{day}}$$



$23.44 - 1.548$
$= \underline{\underline{21.902}}$




$\theta = 5.14 - 6.68$
$\theta_1 = -1.548$
$\theta_2 = 1.548$

$\Gamma = 0°$

$\Omega = 30°$

$i = 21.902$

$\varepsilon = 1.548$

$$\Omega = \cos^{-1}\left[\frac{n_x}{n}\right]$$

$$\beta(t) = \sin^{-1}\left(\cos(1.548)\sin(21.902)\sin((30°-0°)) + \sin(1.548)\cos(21.902)\right)$$
$$= -1.504078759$$
$$= +3.14 = 1.635921241$$